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Radio frequency identification (RFID) has existed for a number of years, with some in the industry believing that the industry had its start during World War II with the advent of the Identification Friend or Foe (IFF) method of identifying allied aircraft. In this system, a transponder within the aircraft detected the radar energy from the shore-based radar systems and responded with a specific encoded signal as a return. While this may have been the impetus of RFID, the first commercial applications had to wait on advancing technology developments to enable success.

The first successful commercial applications were simple single-bit devices referred to as electronic article surveillance (EAS) systems used to detect articles leaving a store that were not purchased. Articles would have a tag attached, with the single bit set "active," that could be detected by readers set at the exits of the store. If an article was

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paid for, the clerk would remove the tag, using a special tool, thus allowing the article to move through the read zone without setting an alarm. This type of system is still in heavy use today but, due to technology advancements, it can be included without the cumbersome attached tag, with the tag being part of the wrapping or cover. The tagged article is passed over a device that resets the tag to "inactive," allowing the article to be removed from the store.

RFID systems are relatively simple (see Figures 1–3), consisting of readers and tags. Readers radiate a signal and receive responses from tags. Readers may operate in one of a number of frequencies ranging from 125 KHz to 5.8 GHz. Tags may be classed as passive or active,

read only or read-write, and with or without batteries. The range at which a tag may be read and the speed at which it will be read will vary according to the frequency, power, and the number of bits of intelligence being passed. As a result, access control afforded in plastic badges will typically have a read range of a few inches, while a toll road application will have a read range of 100 ft, or more, and at highway speeds.

Yesterday

The genesis of the modern-day RFID system can be found in the patent granted to Mario Cardullo in 1973, followed by a number of patents issued to Charles Walton in 1973 and again in 1974. These patents were followed by a number of engineering patents by Alfred Koelle, Steven Depp, and Dr. Jeremy Landt. Between these principals there are more than 60 patents on RFID systems.

Sensormatic and Checkpoint were two of the leading companies in the development of EAS systems and remain as leaders in the application of such systems.

Fig. 1 A complete RFID unit, including an enclosed antenna, typically used in toll roads, parking, gate control, and similar applications. (Photo courtesy of Sirit, Inc.)

The earliest applications for RFID were mostly concerned with tracking of animals, both in the United States and Europe. A typical tag was the size of a large grain of rice and the tag was encoded with a unique identification serial number. The tags were placed under the skin of the animal to be tracked or in a tag that was then applied to the ear of the animal. The primary drivers for animal tracking were in the positive identification of each animal for feeding (weight gain) and in treating any type of illnesses (corrective medicine). Most animal tracking tags are relatively short-range devices that can be read by either stationary or portable readers.

Some of the early advancements were funded by the U.S. Agriculture Department with an emphasis on remote identification of cattle on the open range. Amtech was formed by a number of scientists at the Los Alamos Laboratory, in New Mexico, with one of the key people being Dr. Jeremy Landt. The system developed at the time was known as a backscatter system, where the tag detected the transmitted signal and reflected the base signal modified by the data content of the tag. The system operated in the 900–918-MHz frequency band and could be read to a distance of approximately 100 ft and speeds up to 60 mi/h. It was the latter two characteristics that opened new

applications in electronic toll collection (ETC) and weigh station bypass.

Today

There are a number of RFID market applications today. They include electronic toll collection, weigh station bypass, railroad car tracking, curb space control, personnel access control, inventory management, process control, special event control, livestock tracking, and product identification and protection. This is not an exhaustive list.

Product identification and protection is most often seen as part of the EAS approach but can be extended to having the tag cross-referenced to the inventory tracking system, much like a bar code. The extended application provides an additional rationale for the investment costs justification. The capability of the RFID system to be used for multiple applications can, in many cases, provide the necessary impetus to move into an active project.

There are privacy arguments against the use of RFID for item identification, raising concerns that "someone" will now know what you are buying or where you live, among other concerns. Unless you purchase with a credit card, debit card, or check, there is no active correlation taking place within the RFID system. If the correlation can be made, for some purpose, the same holds true for the bar code on the purchased item. There has to be an extended effort to make the coded items have any personal reference. The coded tag, or bar code, is primarily a pointer into a remote database to be used for inventory control and product ordering, nothing more.

Livestock tracking using RFID has expanded considerably over the years. In the original applications, primarily it was livestock (cattle, sheep, and hogs) that were tagged for identification and tracking. That has expanded into such areas as identification of race horses, high-value animals (pure breed, specialty animals), and even pets. The latter use has been endorsed by many veterinarians as a positive means of identifying the family pet in case it wanders or is stolen.

There are a number of applications today that would be classed as event control. For example, in a cross-country race or a marathon, the participants may wear ankle bracelets that contain RFID tags. These tags can allow readers to be placed along the course to maintain contact with the runners and can be used to

confirm that the runners participated legally, as well as identifying the winners as they cross the finish line. RFID tags can also be used at ski resorts, where the tag identifies and allows skiers to use the lifts. While one may not consider it an event, there are now RFID tags inserted into keys enabling a car to be started (or disabled without the correct tag ID.)

There are a number of system solutions in the manufacturing sector that use RFID as part of the process control. Such use can ensure proper sequence of operations, that the proper parts are available and in place, and it can be used with the proper system and tag selection, as dynamic data carriers as the product moves through the assembly process.

One of the fastest growing markets for RFID application can be found in present day supermarkets. Wal-Mart has become a leader in the application of RFID in its industry segment. The tags are used for EAS functions, sales information, inventory control, and stocking. Even with the dynamic growth of RFID, the original EAS one-bit devices continue to find new applications because of the relatively low cost of the system.

RFID has shown to be a valued addition to the personnel access control application. While the initial concept was to allow doors to be remotely enabled through the presentation of an encoded badge, that was merely the starting point for the technology. There are systems active that will monitor patients in hospitals, alerting staff if a patient leaves the area or the building.

Fig. 2 An RFID transmitter/receiver using an external antenna interface, typically used in indoor applications such as inventory control and personnel access. (Photo courtesy of Sirit, Inc.)

There are also systems that can provide real-time location of staff for emergency notification without a general broadcast being required. The system can also be expanded such that movement of equipment and personnel can be correlated, thus becoming an anti-theft system (even though some may call it an invasion of personal privacy). Such a system, combined with appropriate databases and cameras, can put a stop to the loss of expensive equipment. Such increased general use of the RFID system can again help in the justification process on the cost of the system.

While most businesses don't have to worry about curb space, that doesn't hold true for airports. With personal vehicles curb side, taxis dropping and picking up passengers, hotel and other business courtesy vans, car rental vans, and airport parking vans, the use of available curb space becomes a major concern. Some airports are now looking at limiting the number and types of vehicles having access to their curbside space, charging for the number of times used and/or the length of the time used. In a similar application, parking facilities are now using RFID to control ingress and egress from the parking facility and, in some instances, using the tag information to access and debit the user's account.

Within the rail industry, identification and location of rail cars is extremely important, as fees associated with the use of other railroad assets must be determined. One approach to the identification of rail cars was through the use of bar codes imprinted on the side of the cars. That was found to be inadequate, as the bar codes were often obscured by grime, snow, or ice. An alternative solution using RFID was proposed and accepted, and the Amtech rail tag was placed on both sides of the various rail assets, allowing them to be tracked under extreme conditions. Today, all rail assets are tagged, and as the asset passes strategically located readers, the information can be passed to the central tracking office for its use in fee assessment.

Perhaps one of the more interesting applications of RFID technology is found in the weigh-station bypass program. It was first put forward in 1983 and then implemented in 1991 in six western states and British Columbia, under the name of the Crescent Project. The project was a combination of automatic vehicle identification (AVI),

weigh-in-motion (WIM), automatic vehicle classification (AVC), and integrated networks and databases—all combining to aid in commercial vehicle operations (CVO) within the various state CVO departments. With the success of the Crescent Project, Lockheed began its current PrePass program, which is now in 30 states with more than 290 operational sites. According to the PrePass Web site, it has recorded more than 300 million approved bypasses, with an estimated savings to the trucking associations and states of more than US$2.2 billion.

In another implementation of the CVO application, the I-75 Corridor Project installed over 100 readers at the weigh stations along Interstate Highway I-75, from Punta Gorda, Florida, to Toronto, Canada. A large number of these sites have since become part of the PrePass program.

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One other group, which will be discussed in more detail, is the Inter Agency Group (IAG), a consortium of states in the northeastern United States, starting with New York, New Jersey, Connecticut, and Pennsylvania toll, bridge, and tunnel operators, and since expanded to 25 agencies in 14 states. While the IAG emphasis was originally centered on toll way operations, it has been extended to include CVO.

The final application to be discussed is that of toll operations, where operations may include roadways, tunnels, or bridges. As noted, the IAG is a consortium in the northeast part of the United States. One of their concerns in implementing RFID solutions was the protocol to be used and the ability to exchange information across state lines. The manufacturer that was chosen as the source for the IAG tags and readers was Mark IV Industries, a Canadian company, now known as Kapsch TrafficCom. The Mark IV Industries Fusion Tag operated on a proprietary protocol and was an active tag. The other major supplier, at the time, was Amtech (now Transcore), whose tag operated on

Fig. 3 An RFID window mount tag, or transponder, typically used in toll roads, parking, gate control, and similar applications. (Photo courtesy of Sirit, Inc.)

the backscatter principle, a completely different protocol from that offered by Mark IV Industries. Transcore has implemented their RFID technology in a number of toll systems in Oklahoma, Texas, Louisiana, and Missouri.

Tomorrow

RFID has made major advances in a number of applications, but there are problems that continue to require answers. Included in those problems are concerns for privacy, common protocols, costs, and qualified solutions.

The concerns for privacy, while questioned in current applications such as toll ways, becomes more vocal when the tagging of drivers licenses and passports are mentioned. The vision of "Big Brother" knowing your every move is hyped, causing vocal outcry against such technology. The counter to that is that if the technology can reduce the frequency and use of forged credentials, with limits on the data encoded, society would be better served.

As RFID applications continue to expand, there will be an ever-increasing need to find commonality in tag protocols, at least within a specific application (i.e., tolls, weigh station bypass, access control). Some minor progress has been made with the introduction of the Mark IV Industries Fusion II tag, which can operate in two modes: the Mark IV Industries proprietary protocol and the PrePass protocol. That still leaves the Transcore backscatter protocol to be incorporated or a completely different, common protocol to be implemented.

The costs of RFID systems continues to decrease, with tag prices, originally found in the US$50–$100 per tag price, now more common in the less than US$1 per tag price. Many tags are reusable, being able to move from asset to asset, with the difference accounted for in the database rather than as an entry into the tag's memory. The continued

same fall during the evenings, plus my past experience in other math fields. At the time it seemed that I was just in the right place at the right time, but later, when I did a term in hiring for Bell Canada, I learned that they hired me for this position because I had demonstrated both strong technical skills in the past as well as an ability to work with people and to teach others mathematical material. Part of this job involved supporting people who used my programs and equations to design customer networks, and everything had to be carefully explained to them. Just being able to do the design was not enough for this position.

• Later in IEEE work, I was asked to volunteer for many positions for which, at the time, I felt I was not really qualified. As it turned out, all were wonderful and great learning experiences, which provided more experience that has been useful in my various jobs.

Have there been disappointments along the way? Many, of course. I suspect that everyone has had a fair share of these. There were jobs I really wanted to have, which went to others. The others did well in these jobs. I believe I would also have done well, but I ended up elsewhere and gained from the other positions in any case. If I were starting again, would I go into engineering? Teaching? Management? Absolutely. For me, these were all great experiences and though all involved hard work and focus, it was well worth it for the personal value I received in return.

RFID: Yesterday, today, and tomorrow

movement of the cost to the point that tags are commonly found in the US$0.10–$0.25 per tag will provide many additional applications to cross the boundary needed to justify the return on investment.

There is a large number of suppliers of RFID technology and an almost equal number of distributors, integrators, and application software suppliers. The trick is to find the supplier of the RFID technology and the systems integrator/application program to fit the requirements of the application without having to resort to major changes in procedures. The need to adapt an application, or technology, to fit the requirements may be extensive, removing the project from the realm of consideration. Users must shop carefully to ensure their requirements and the specifications of the equipment and application map to each other.

There are many more applications that are either in their infancy or not yet started. As previously mentioned, drivers licenses and passports are just beginning to be considered (or early in implementation). Inclusion of tags buried into book covers is a future application, again being started, but not yet in general use. Another consideration that has found some use is in the identification of office files, especially in legal areas where file sensitivity is required. In this latter application, not only could the file be marked, but the person moving it could be identified as well as entry or exit from the room or facility.

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Read more about it

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Raymond E. Floyd (r.floyd@ieee.org) earned a B.S.E.E. from the Florida Institute of Technology in 1970, an M.S.E.E. from Florida Atlantic University in 1977, and a Ph.D. in industrial management from California Coast University in 2009. He spent six years with Philco-Ford as a senior training instructor and 26 years with IBM as a senior engineer, retiring in 1992. He is a Life Senior Member of the IEEE, a senior member of the Society of Manufacturing Engineers, and a member of the Society of Petroleum Engineers. He has served as a program evaluator for the Technology Accreditation Commission of ABET (TAC/ABET) for 15 years and is a member of the Committee on Technology Accreditation Activities.